PAV Condition Time versus Field Ageing and Pavement Depth

Braden T. Smith

Paving Asphalt Specialist at Hunt Refining Company

Mississippi State University Alumni

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Smith, B.T., I.L. Howard, W. S. Jordan, III, C. Daranga, G. L. Baumgardner (2017). “Comparing Pressure Aging Vessel Time to Field Aging of Binder as a Function of Pavement Depth and Time.” Submitted to Transportation Research Board for Peer Review, Paper Number 18-04401.

Experiment Background

Ideally binder conditioning methods would provide

1. fair means for classifying binders for purchasing (AASHTO M320)
2. method to directly consider property changes as binders leave producers, are added to paving mixes, and field aged (not possible with 1 protocol)

AASHTO M320 calls for AASHTO T240 Rolling Thin Film Oven (RTFO) followed by AASHTO R28 Pressure Aging Vessel (PAV).

- RTFO – short term property changes from construction
- PAV – longer term property changes from field ageing
  - 20 hours intended to simulate 5 to 10 years – under investigation

How many PAV hours are necessary to simulate field ageing?

Test Section Description

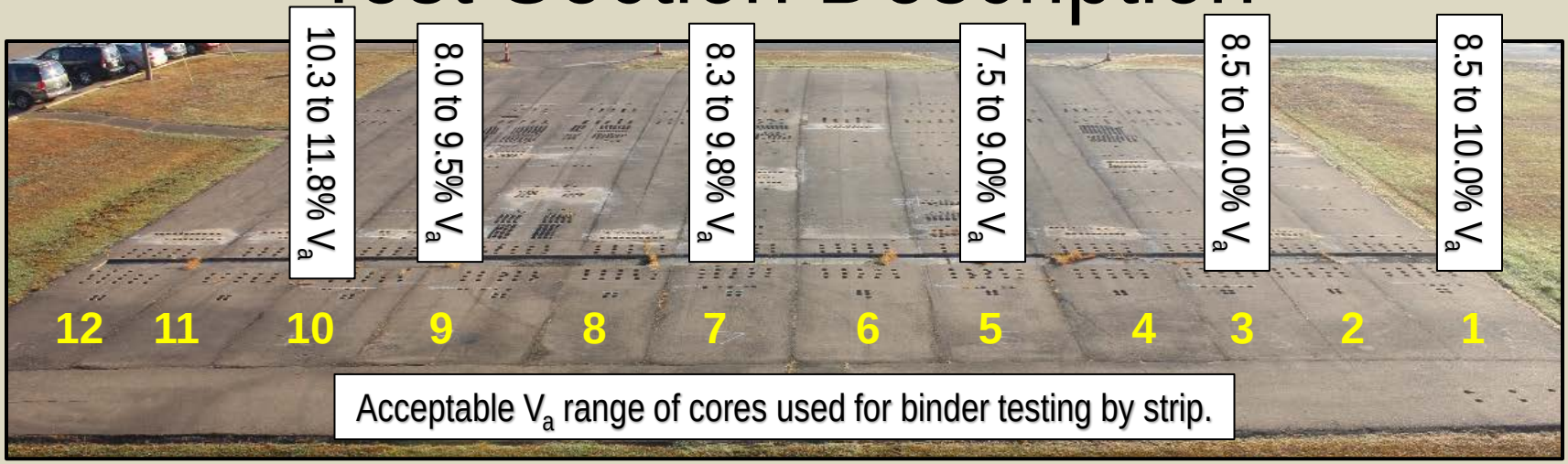
November 2016

Columbus, MS Section Built November 1-3, 2011

- Built for emergency paving demonstration
- 5.4% PG 67-22 (Neat, Foamed, and Evotherm)
- 15% RAP, 1% Hydrated lime, 39% Crushed Gravel, 35% Limestone, and 10% Sand
- 36 field aged binders recovered (Strips 1, 3, 5, 7, 9, and 10)

Strips hauled for approximately 1 or 6 hours

Test Section Description



Test Section Advantages

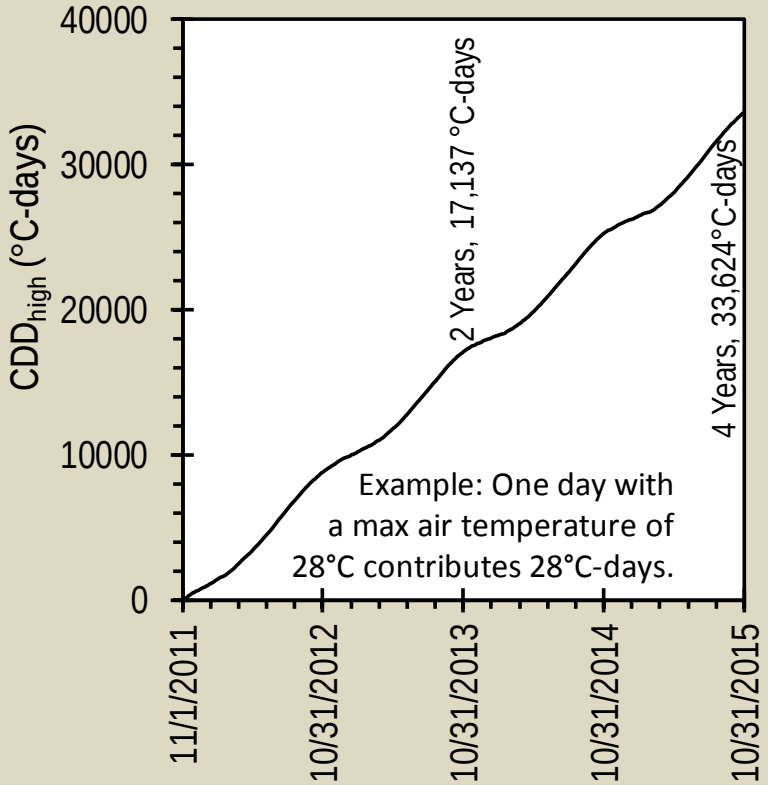
- Original binders were sampled the day of construction
- Field ageing for binder – 4 years
- Single lift was 7 cm thick on average

Test Section Challenges

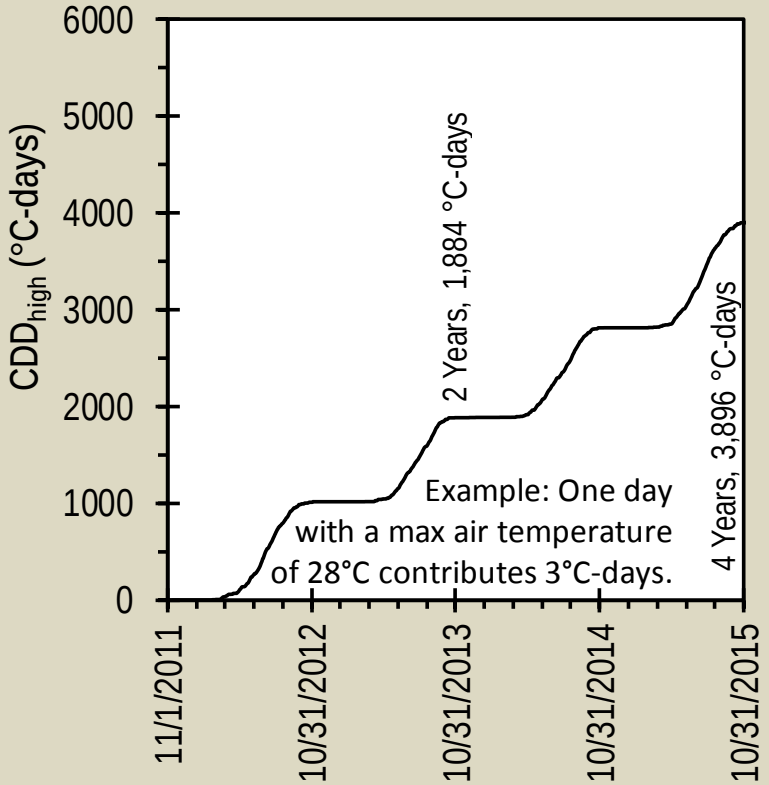
- Was not built for field ageing (V_a varied across test strips)
- Only materials sampled at construction were original binders and mix (cores and loose)

Weather Data

CDD_{high} (°C-days) – accumulation of daily high air temperature data
- daily high air temperatures < 0°C excluded from CDD_{high}



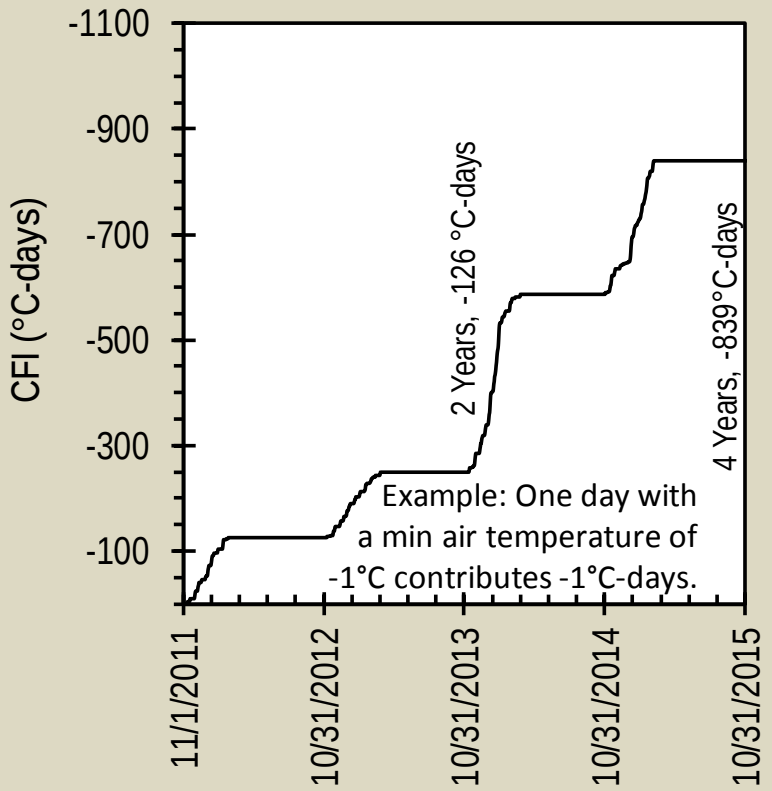
high air temperatures > 0°C



high air temperatures > 25°C

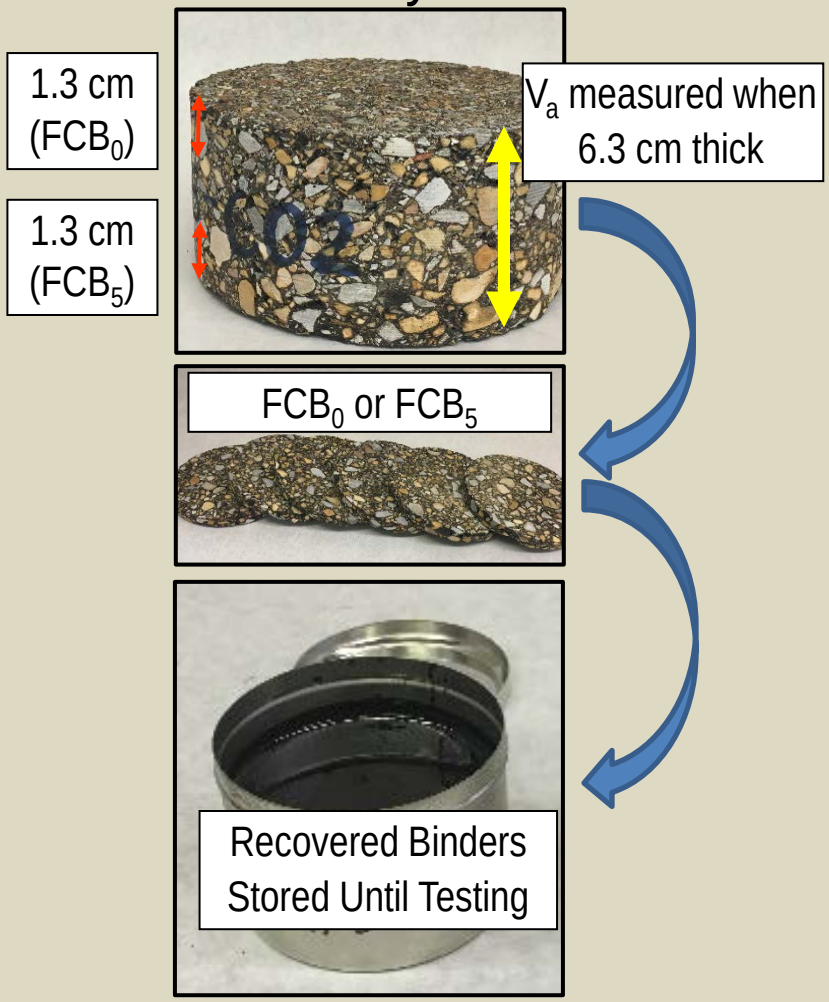
Weather Data

CFI (°C-days) – accumulation of daily low air temperatures below 0°C



Binder Cases Considered

FCB Recovery Process



36 Field Core Binders (FCBs)

- 0 year, 2 year, 4 year
- 6 Test Strips (Strip 1, 3, 5, 7, 9, and 10)
- 2 Depths
  - Top (0 cm to 1.3 cm) – FCB_0
  - Bottom (5 cm to 6.3 cm) – FCB_5

16 As-Received Binders (ARBs)

- PG 67-22 Neat and with 0.5% Evotherm
- As-Received (No laboratory conditioning)
- RTFO + 7 PAV times Considered
- 0, 10, 20, 30, 40, 60,or 80 hours of PAV

Testing Program

High Temperature

- AASHTO T315 – 25 mm DSR Critical Temperature ($T_c(DSR_{25})$)
  - $G^*/\sin\delta$ = 2.20 kPa

Intermediate Temperature

- ASTM D5 – Penetration at 25°C
- AASHTO T315 – 8 mm DSR Critical Temperature ($T_c(DSR_8)$)
  - $G^*\sin\delta$ = 5.00 MPa

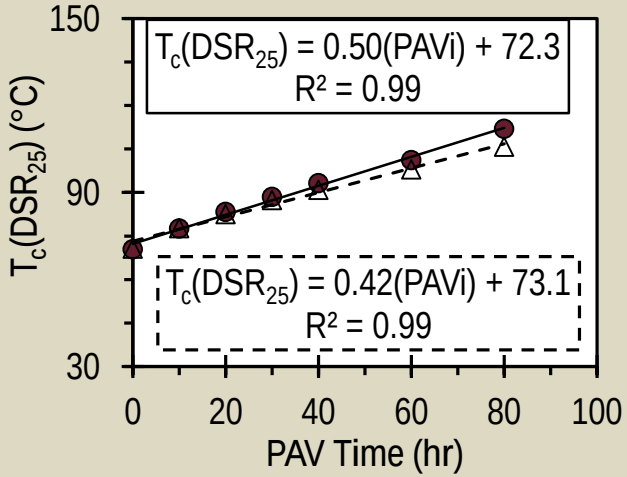
Low Temperature

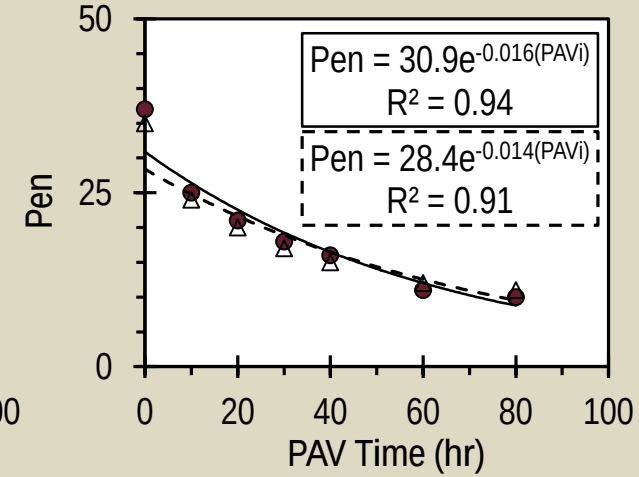
- AASHTO T313 – BBR Critical Temperatures for Stiffness ($T_c(BBR_S)$) and *m*-value ($T_c(BBR_m)$)
  - Stiffness = 300 MPa & *m*-value = 0.300
- ΔT_c; $T_c(BBR_S)$-$T_c(BBR_m)$

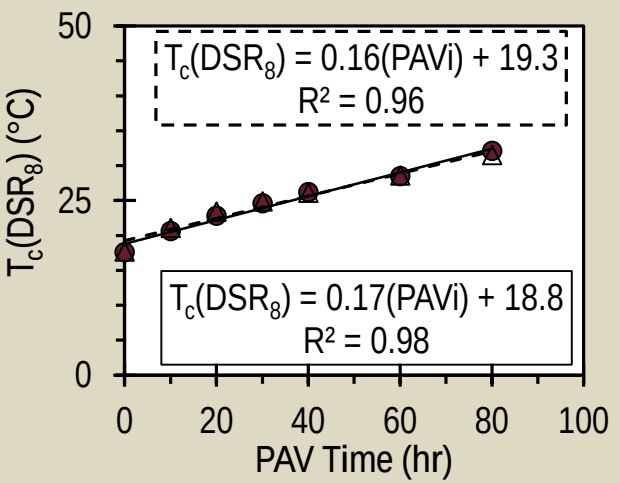
Chemical

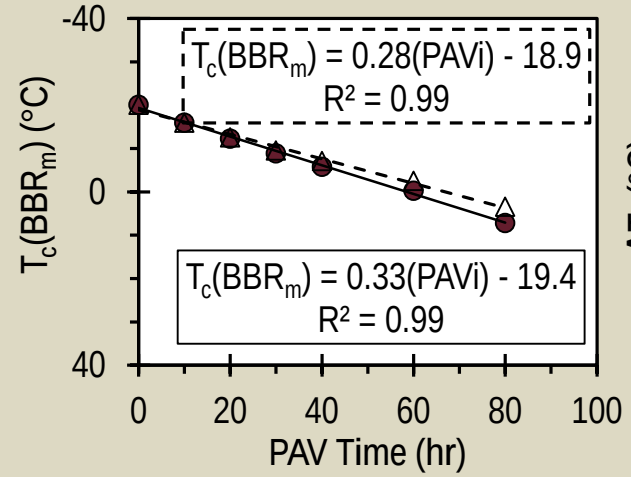
- Carbonyl Index Plus Sulfoxide Index (CI+SI) from Fourier Transform Infrared Spectroscopy (FTIR)

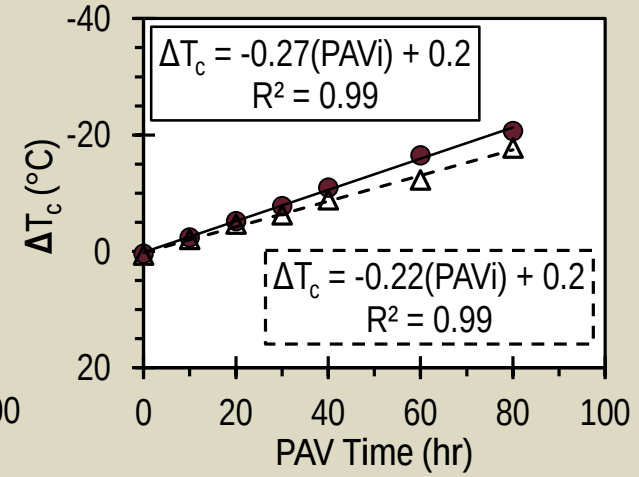
PAV Conditioned Behaviors

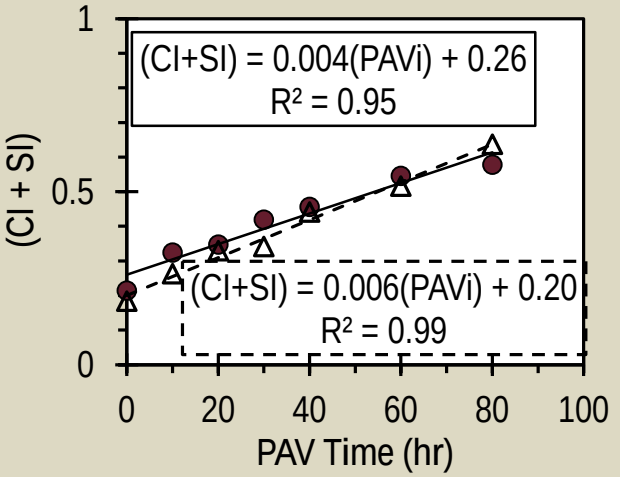




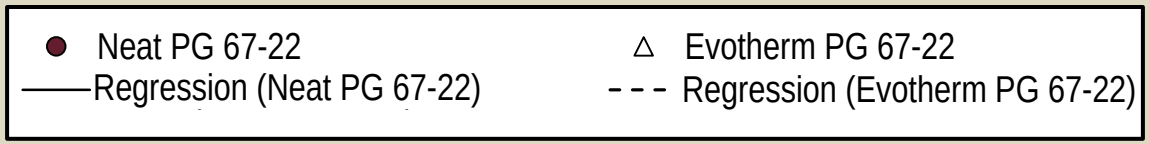








Behaviors were predictable, and Evotherm slowed the effects of PAV conditioning.
Trends used to relate field aged properties to PAV time.



Field Core Binder Properties

High Temperature Properties			$T_c(DSR_{25})$ (°C)		
Mix	Strip	Depth	0 Year	2 Year	4 Year
HMA	1	FCB_0	79.3	87.5	94.1
		FCB_5	75.7	74.7	84.7
	3	FCB_0	80.1	90.0	96.4
		FCB_5	79.6	83.2	83.8
Foam	5	FCB_0	73.3	81.6	92.6
		FCB_5	70.8	72.2	82.6
	7	FCB_0	71.9	87.1	95.0
		FCB_5	77.3	76.2	85.6
Evotherm	9	FCB_0	70.2	85.8	93.7
		FCB_5	74.4	75.7	78.8
	10	FCB_0	76.5	88.9	96.0
		FCB_5	77.2	81.4	81.0

Field Core Binder Properties

Intermediate Temperature Properties			$T_c(DSR_8)$ (°C)			Penetration at 25°C (dmm)		
Mix	Strip	Depth	0 Year	2 Year	4 Year	0 Year	2 Year	4 Year
HMA	1	FCB_0	20.8	25.4	28.0	23	15	10
		FCB_5	17.8	15.9	23.3	29	41	17
	3	FCB_0	19.5	25.4	28.3	27	16	10
		FCB_5	19.5	23.1	21.6	25	21	19
Foam	5	FCB_0	16.0	20.1	28.4	28	25	11
		FCB_5	16.7	16.1	23.2	50	45	18
	7	FCB_0	14.5	23.9	29.6	49	17	11
		FCB_5	18.9	17.9	23.8	29	30	16
Evotherm	9	FCB_0	12.5	23.8	29.6	48	16	10
		FCB_5	17.4	17.7	20.3	36	25	22
	10	FCB_0	18.9	26.1	30.8	26	15	10
		FCB_5	18.9	23.8	21.8	28	22	20

Field Core Binder Properties

Low Temperature Properties			$T_c(BBR_m)$ (°C)			ΔT_c (°C)		
Mix	Strip	Depth	0 Year	2 Year	4 Year	0 Year	2 Year	4 Year
HMA	1	FCB_0	-19.9	-14.4	-9.5	-2.1	-5.3	-7.3
		FCB_5	-21.7	-25.7	-14.7	-1.5	-1.0	-4.9
	3	FCB_0	-20.4	-14.7	-8.1	-2.7	-5.0	-7.5
		FCB_5	-17.6	-17.3	-17.6	-3.6	-3.6	-3.4
Foam	5	FCB_0	-24.3	-18.4	-9.6	-1.3	-5.0	-7.0
		FCB_5	-25.7	-24.7	-15.9	-1.3	-1.3	-2.7
	7	FCB_0	-26.0	-14.5	-7.5	-2.0	-5.3	-8.4
		FCB_5	-20.3	-21.9	-13.6	-2.4	-1.3	-6.0
Evotherm	9	FCB_0	-26.3	-14.8	-7.9	-1.1	-5.1	-7.6
		FCB_5	-22.3	-21.0	-19.2	-1.8	-2.1	-2.0
	10	FCB_0	-20.2	-12.9	-6.1	-2.7	-5.7	-7.9
		FCB_5	-18.9	-16.6	-18.2	-2.9	-3.0	-1.8

Field Core Binder Properties

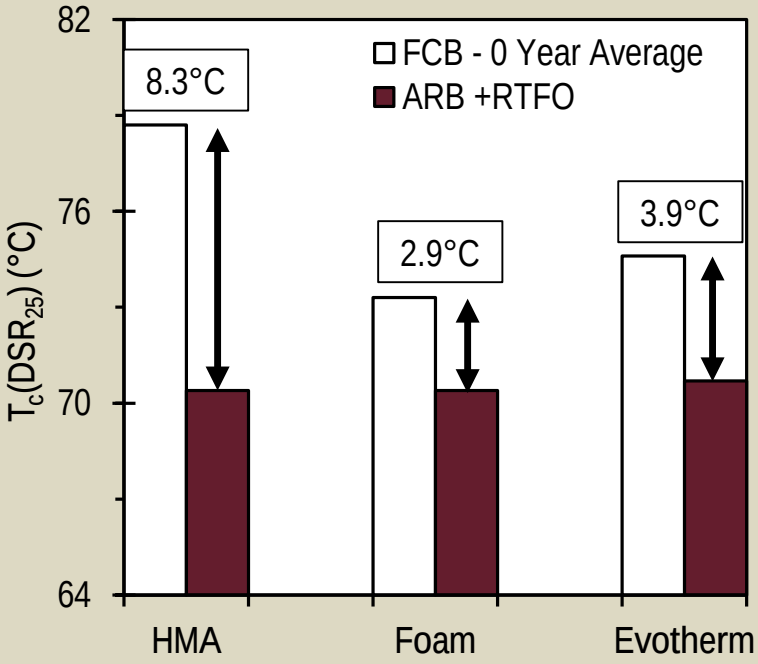
Chemical			(CI+SI)		
Mix	Strip	Depth	0 Year	2 Year	4 Year
HMA	1	FCB_0	0.57	0.49	0.80
		FCB_5	0.56	0.56	0.69
	3	FCB_0	0.47	0.69	0.76
		FCB_5	0.57	---	0.61
Foam	5	FCB_0	0.56	0.68	0.88
		FCB_5	0.61	0.53	0.56
	7	FCB_0	0.56	0.77	1.03
		FCB_5	0.60	0.60	0.75
Evotherm	9	FCB_0	0.57	0.67	0.70
		FCB_5	0.60	0.55	0.59
	10	FCB_0	0.56	0.69	0.84
		FCB_5	0.58	0.57	0.60

--- outlier removed

Mixture Offset Determination

Need – To compare ARB to FCB without materials for direct measurement.

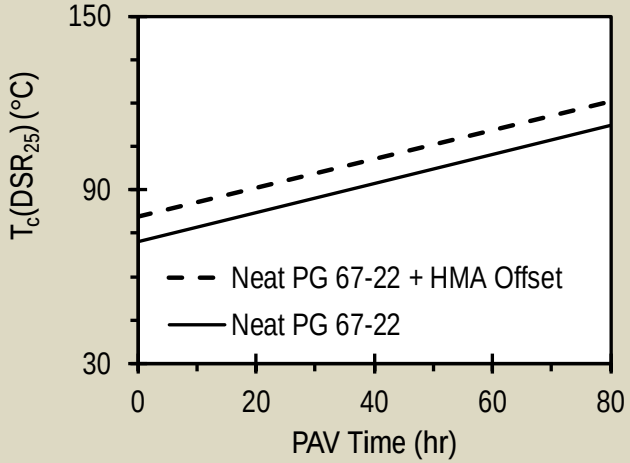
Assumption – The difference between 0 year FCB binders and RTFO conditioned as-received binders were used to shift as-received binder PAV time curves.

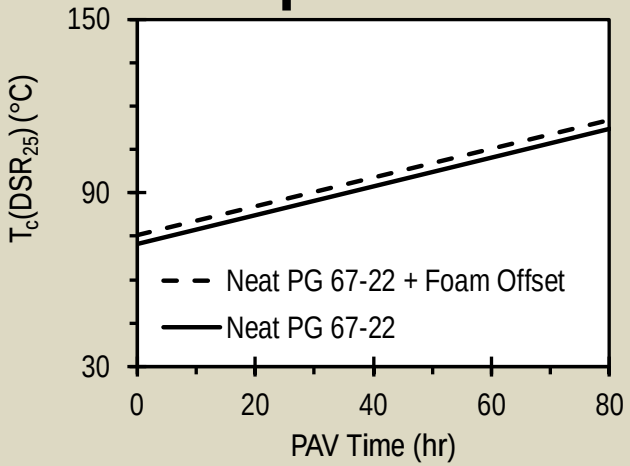


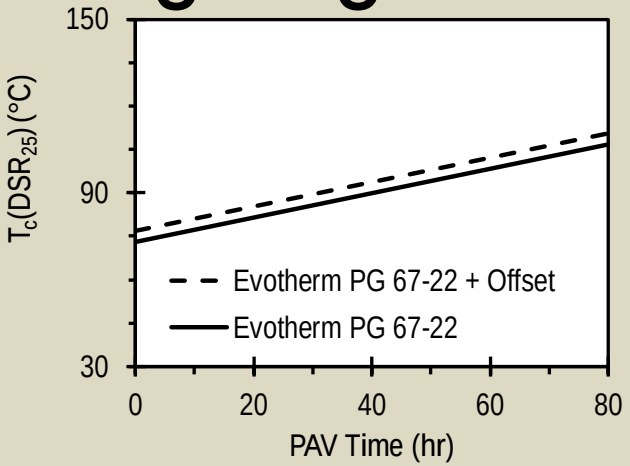
Property Offsets from ARB + RTFO to 0 Year FCB

Mix	HMA	Foam	Evotherm
$T_c(DSR_{25})$ (°C)	8.3	2.9	3.9
Pen (dmm)	-11	+2	-1
$T_c(DSR_8)$ (°C)	1.8	-1.1	-0.8
$T_c(BBR_m)$ (°C)	0.2	-4.0	-1.8
ΔT_c (°C)	-2.9	-2.2	-2.7
(CI+SI)	0.33	0.37	0.40

PAV Time Comparison to Ageing





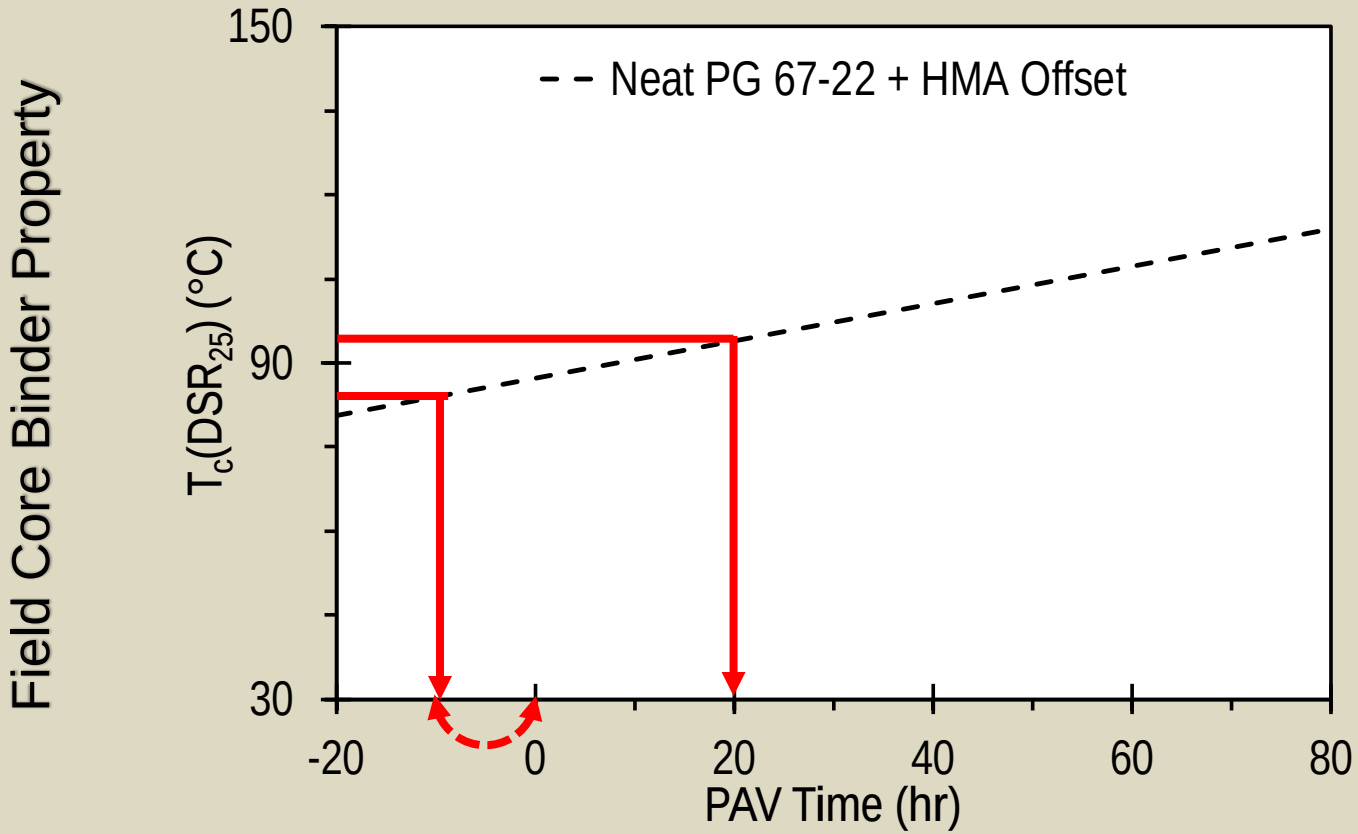


↑ $T_c(DSR_{25})$ curves for examples of modified curves ↑

Modified Curves Solved for PAV Time		
HMA	Foam	Evotherm
= $(T_c(DSR_{25})-80.6)(1/0.50)$	= $(T_c(DSR_{25})-75.2)(1/0.50)$	= $(T_c(DSR_{25})-77.0)(1/0.42)$
= ln[(*Pen*+11)/30.9](-1/0.016)	= ln[(*Pen*-2)/30.9](-1/0.016)	= ln[(*Pen*+1)/28.4](-1/0.014)
= $(T_c(DSR_8)-20.6)(1/0.17)$	= $(T_c(DSR_8)-17.7)(1/0.17)$	= $(T_c(DSR_8)-18.5)(1/0.16)$
= $(T_c(BBR_m)+19.2)(1/0.33)$	= $(T_c(BBR_m)+23.4)(1/0.33)$	= $(T_c(BBR_m)+20.7)$ (1/0.28)
= $(\Delta T_c+2.7)(-1/0.27)$	= $(\Delta T_c+2.0)(-1/0.27)$	= $(\Delta T_c+2.5)(-1/0.22)$
= ((CI+SI)-0.59)(1/0.004)	= ((CI+SI)-0.63)(1/0.004)	= ((CI+SI)-0.61)(1/0.006)

-- Equations use FCB properties to determine PAV Time in Hours

PAV Time Comparison to Ageing



- FCB properties compared to PAV Time
- FCB properties resulting in negative PAV times considered as 0 hours

Field Ages Related to PAV Times

Strip		2 Year FCB$_0$	2 Year FCB$_5$	4 Year FCB$_0$	4 Year FCB$_5$		2 Year FCB$_0$	2 Year FCB$_5$	4 Year FCB$_0$	4 Year FCB$_5$
1	$T_c(DSR_{25})$	14	0*	27	8	$T_c(BBR_m)$	15	0*	29	14
3		19	5	32	6		14	6	34	5
5		13	0*	35	15		15	0*	42	23
6		24	2	40	21		27	5	48	30
7		21	0*	40	4		21	0*	46	5
10		28	10	45	10		28	15	52	9
1	*Pen*	11	0*	24	6	ΔT_c	10	0*	17	8
3		8	0*	24	2		9	3	18	3
5		18	0*	77	41		11	0*	19	3
6		45	6	77	49		12	0*	24	15
7		37	6	68	15		12	0*	23	0*
10		41	15	68	22		15	2	25	0*
1	$T_c(DSR_8)$	28	0*	44	16	(CI+SI)	0	0*	52	25
3		28	15	45	6		25	**	42	5
5		14	0*	63	32		12	0*	62	0*
6		36	1	70	36		35	0*	100	30
7		33	0*	69	11		10	0*	15	0*
10		48	33	77	21		14	0*	39	0*

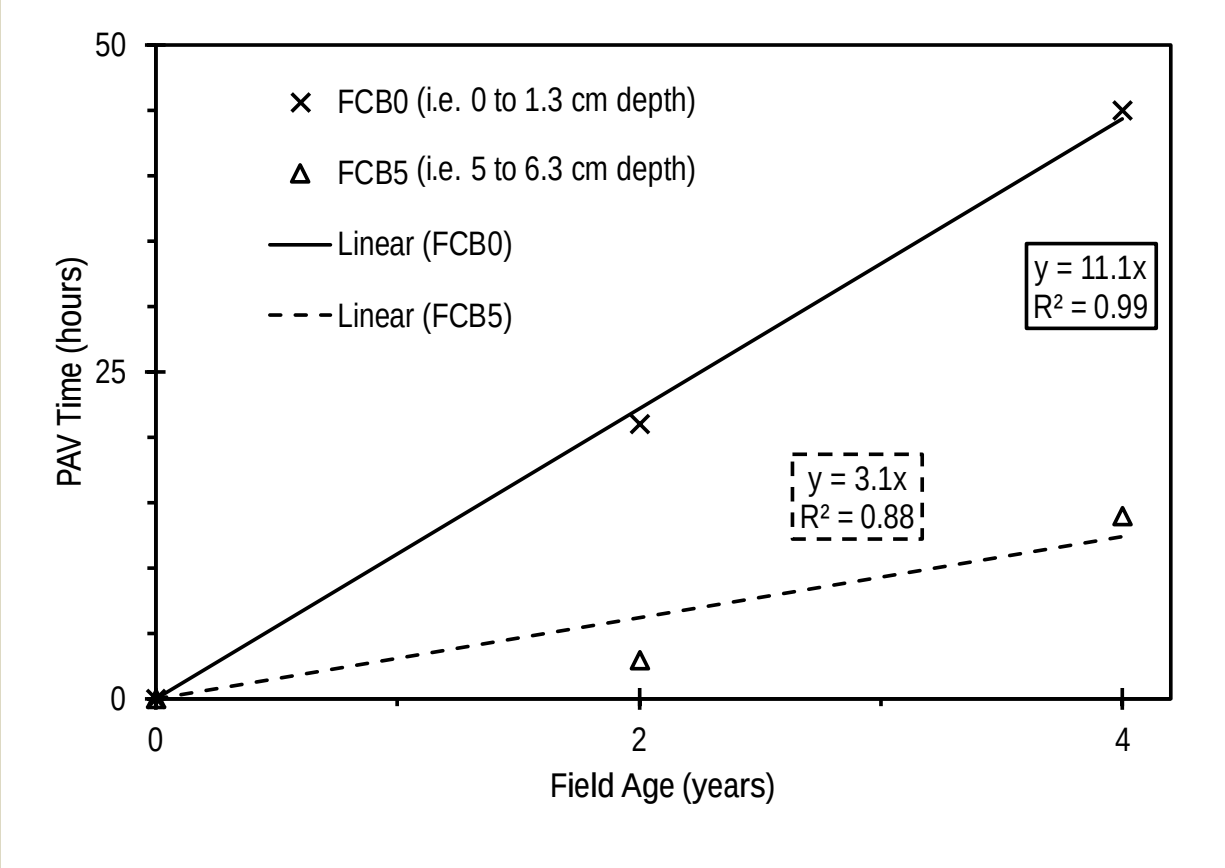
PAV Times reported in hours; * Negative values replaced with 0; ** Outlier removed

Field Ages Related to PAV Times

	2 Year				4 Year			
	FCB_0		FCB_5		FCB_0		FCB_5	
Property	Range	Average	Range	Average	Range	Average	Range	Average
$T_c(DSR_{25})$	8 to 45	27	0 to 15	5	24 to 77	56	2 to 49	23
Pen	13 to 28	20	0 to 10	3	27 to 45	37	4 to 21	11
$T_c(DSR_8)$	14 to 48	31	0 to 33	8	44 to 77	61	6 to 36	20
$T_c(BBR_m)$	14 to 28	20	0 to 15	4	29 to 52	42	5 to 30	14
ΔT_c	9 to 15	12	0 to 3	1	17 to 25	21	0 to 15	5
(CI+SI)	0 to 35	16	0 to 0	0	15 to 100	52	0 to 30	10
Collective	*0 to 48*	*21*	*0 to 33*	*3*	*15 to 100*	*45*	*0 to 49*	*14*

PAV Times reported in hours

Behavior with Depth



- Pavement surface required approximately 3 times more conditioning time than binder 5 cm below the surface.
- 20 PAV hours could simulate 6.5 years of field aging in binders at depth.

Summary and Recommendation

- For the test section considered, PAV times to best simulate 2 years and 4 years were respectively
  - 21 hours and 45 hours at the pavement surface
  - 3 hours and 14 hours at depth of 5 cm
  - PAV times of 11 hours per year (surface) and 3 hours per year (at depth)
- Recommend that these values be considered alongside current marketplace factors (e.g. more severe environmental exposure) when moving forward with standards and specifications discussions.

Thank You

Questions?

Braden T. Smith, PhD
Hunt Refining Company
btsmith@huntrefining.com